# APPENDIX 4-A

## TECHNICAL MEMORANDUM, PROCESS USED TO SELECT WELL LOCATIONS

# TECHNICAL MEMORANDUM

**DATE:** December 16, 2014 **PROJECT NO.** 350.0092.000

**TO:** K. Bill Clark, NewFields

**FROM:** Joel Jacobson, NewFields

**SUBJECT:** Process Used to Select Well Locations, Groundwater Monitoring Program, Pinedale Anticline Project Area, Sublette County, Wyoming

This technical memorandum documents the methods and results for selecting monitoring well locations that will be used for the Groundwater Pollution Prevention, Monitoring and Response Action Plan (Plan) for the Pinedale Anticline Project Area (PAPA), a natural gas development in Sublette County, Wyoming. Goals and objectives for the Plan were approved by the BLM Pinedale Field Office on June 19th, 2014. One of the Plan's goals is to establish a Groundwater Monitoring Program capable of identifying impacts from natural gas activities based on previous groundwater characterization studies and differing levels of risk in different areas of the PAPA. The Program must monitor groundwater for constituents that are: most indicative of impacts from natural gas activities; most likely to appear first at monitoring sites; and, most hazardous to public health and the environment. Specific objectives for this goal related to monitoring locations are:

- ***Objective O2.3*** *- Develop a tiered approach to groundwater monitoring that includes different water quality parameters and sampling frequencies for monitoring locations based on risk, proximity to active development and when a threshold is reached.*
- ***Objective O2.5*** *- Establish groundwater monitoring locations to provide for early detection of potential impacts from oil and gas activities in areas of greatest environmental sensitivity.*
- ***Objective O2.6*** *- Establish groundwater monitoring locations to provide spatial coverage of the PAPA.*

The following sub-sections present the methods and results used to select monitoring locations for the Plan and fulfill the objectives listed above. Figures and tables referenced herein are attached to this memorandum.

## METHODS

Based on work completed independent of (Hamerlinck and Ameson, 1998; Geomatrix, 2002; Bedessem, et. al., 2005) and pursuant to (Geomatrix, 2008; AMEC, 2012; AMEC, 2013a; AMEC, 2013b) BLM's 2008 Record of Decision (BLM, 2008), three areas were selected for monitoring based on current and future natural gas development and risk to potential environmental receptors from natural gas activities in the PAPA. **Figure 4A-1** presents the three areas which include the North Zone, River Corridor Envelope (RCE), and South Zone.

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The methods used to determine monitoring locations for the three zones were designed to produce the minimum number of monitoring locations needed to: 1) ensure adequate capture of impacted groundwater from potential sources; 2) provide early detection of impacted groundwater upgradient of potential receptors; and, 3) fulfill the objectives listed above. Potential sources and receptors in the PAPA were identified as part of the numerical groundwater modeling process (AMEC, 2013a). Potential sources include well pads and their facilities, centralized liquid gathering system (LGS) facilities, LGS pipelines, and injection wells. Potential receptors include the New Fork River and associated floodplain and riverine system, and stock and domestic wells on private land. In addition, it was assumed that any new monitoring wells required to meet the three conditions listed above would be drilled to intercept the first continuously saturated sandstone layer in the Wasatch Hydrostratigraphic Unit (HSU) and into the water table in the Alluvial HSU.

**North and South Zones**

The North and South zones are located north and south of the New Fork River, respectively, and encompass the majority of natural gas development areas in the PAPA (**Figure 4A-1**). Few receptors exist in these zones and groundwater is hosted entirely in the Wasatch HSU. Monitoring locations were determined using spatial analysis of existing wells with the goal of optimizing the existing well network. For this analysis, optimization was defined as a monitoring network that contains the minimum number of wells needed in order to adequately protect potential receptors, provide early detection of potential groundwater degradation, and provide sufficient spatial coverage of the PAPA. Optimization was based on an assumed area of potential degradation which was established using results from AMEC (2012) and AMEC (2013a).

Spatial analysis was performed using Visual Sample Plan (VSP) version 7.0 (PNNL, 2014). The software evaluated positions of existing wells and the zone boundary to calculate the largest unsampled area. If the largest unsampled area was greater than the predetermined extent of potential degradation (see below), it was considered a data gap and a new well was added. If two wells were within an area smaller than the predetermined extent of potential degradation, one of the wells was removed. This method was performed iteratively until the largest unsampled area was reduced to the predetermined extent of potential degradation and there were no redundancies (multiple wells in an area smaller than the predetermined extent of potential degradation) within the zone.

If one or more wells were removed from an area, or a new well was added, the hydrogeologic conceptual model (AMEC, 2012) was considered along with the location of potential sources and receptors. For example, if two wells were located in an area, and one well needed to be removed, the well that was hydraulically down-gradient of the fewest potential sources was removed. Additionally, if a new well was added, it was placed in order to optimize the network (i.e., result in the fewest number of wells) and was positioned hydraulically down-gradient of the most potential sources in the particular sample area.

The area of potential degradation that could occur in the PAPA as a result of natural gas activities was determined using results from AMEC (2012) and AMEC (2013a). AMEC (2012) calculated a maximum contaminant travel distance of 4,400 feet in 110 years (twice the expected development time in the PAPA; refer to BLM [2008]) based on aquifer tests, gradients calculated from groundwater elevations, and effective porosity values of sandstone obtained from literature. AMEC (2013a) determined that potential contamination in the Wasatch HSU could travel 6,000 feet in 110 years based on advective transport modeling. Based on these results, 4,400 feet was used as the radius of potential degradation that could occur in the PAPA as a result of natural gas activities. Therefore, using the method described above, the radius of the largest unsampled area in the North and South zones was reduced to approximately 4,400 feet.

NewFields' electronic database management system (EDMS) was used to identify existing wells in the PAPA that are currently included in the Operator's monitoring program being conducted by Sublette County Conservation District (SCCD) or were study wells installed as part of AMEC (2012). This dataset consisted of 233 wells of which 24 were stock wells, 82 were industrial water supply wells, 84 were domestic wells, and 43 were wells installed as part of AMEC (2012). This dataset was then reduced to only include wells located in the North and South zones. In addition, domestic and stock wells were removed because these were identified as potential receptors. Objective O2.5 (see above) states that monitoring locations should provide early detection of potential impacts. In order to satisfy this objective, groundwater upgradient of potential receptors will be monitored instead of the potential receptors themselves. Finally, wells with known contamination (e.g., wells enrolled in Wyoming Department of Environmental Quality's Voluntary Remediation Program) were removed. This resulted in an initial dataset of 43 existing wells in the North Zone and 26 existing wells in the South Zone (**Figure 4A-2**).

Results of this analysis are presented below in the 'Results' and 'Conclusions' sections of this memorandum.

**River Corridor Envelope (RCE)**

The RCE is located in the center of the PAPA and includes several potential sources and receptors, and near-surface groundwater is present in portions of the Wasatch and Alluvial HSUs. AMEC (2013a) initially defined the RCE using advective transport results from potential sources and receptors (refer to Figure 30 in AMEC, 2013a). The extent of the RCE was refined for this analysis because roads were eliminated as a potential source of groundwater contamination because the LGS was installed by the Operators and vastly reduced the risk of transportation accidents being potential sources. In addition, spills resulting from transportation accidents would be immediately addressed through DEQ and BLM regulation for spill response actions. To fulfill objective O2.5 (see above), the RCE was divided into two different areas, the Alluvial RCE and Wasatch RCE. Monitoring wells in the Alluvial RCE were placed on the four existing natural gas well pads in the floodplain, between the pad and the New Fork River. The location of monitoring wells in the Wasatch RCE was determined using the numerical groundwater model of the PAPA and results from AMEC (2013a).

The initial location of monitoring wells in the Wasatch RCE was outside of the New Fork River floodplain, hydraulically down-gradient of potential sources. Wells were spaced 2,100 feet apart north and south of the New Fork River. Spacing between these wells was determined using results of the hypothetical solute transport model simulating a chloride release from a legacy natural gas well. The 1 milligram per liter (mg/L) isoconcentration contour was used to calculate the maximum width of a potential plume emanating from a natural gas source (refer to Figure 61 in AMEC, 2013a). These initial locations were then optimized based on simulated flow paths from the model and land use/ownership.

Flow paths from the proposed monitoring wells were evaluated using advective transport modeling with reverse particle tracking. Particle tracking involves tracing the movement of imaginary particles in a groundwater flow field based on groundwater velocities and direction. Particles are given a starting location and traced for a defined time period. In reverse particle tracking, particles are placed in a flow field and tracked backward (opposite direction of groundwater flow) along path lines to a potential source. Particle tracking does not take into account the effects of dispersion, adsorption, or biodegradation, and assumes that dissolved contaminants move at the same velocity as groundwater.

Particles were placed around proposed monitoring wells and traced backward through the groundwater flow field. Results were then analyzed to ensure adequate capture of degradation from any potential sources assuming a potential plume width of 2,100 feet. In addition, it was assumed that a release from potential sources close to Paradise Road would not spread to 2,100 feet prior to reaching the floodplain. Monitoring wells were placed directly down-gradient of these sources to ensure capture of any potential degradation.

Finally, the location of potential receptors and land ownership and access were assessed to determine the final location of monitoring wells. In the western portion of the RCE, there are few potential sources so two monitoring wells were placed in this area, hydraulically upgradient of domestic wells. Results of this analysis are presented in the 'Results' and 'Conclusions' sections below.

## RESULTS

The following presents results for the North Zone, South Zone, and RCE based on the methods described above.

### North and South Zones

The images shown below are "screen shots" from the spatial analysis described above. Each step further refined and optimized the monitoring network. The yellow polygon represents either the North or South zone; the September 2010 potentiometric surface and potential natural gas sources are depicted as black lines; and, the existing/proposed monitoring wells are depicted as small blue dots. Each screen shot is accompanied by the value of the largest unsampled area. The goal of the analysis was to reduce the radius of this area to approximately 4,400 feet.

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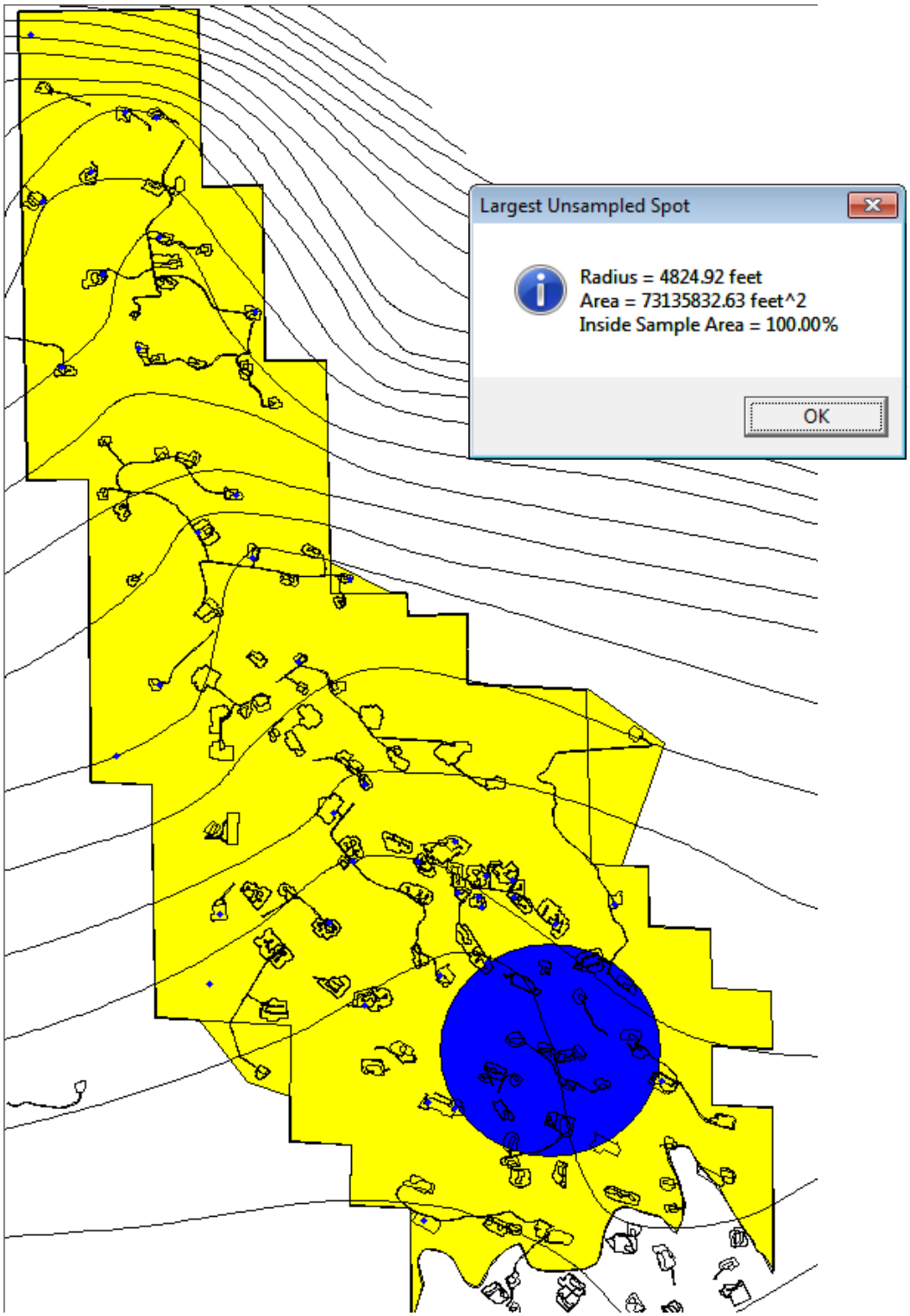
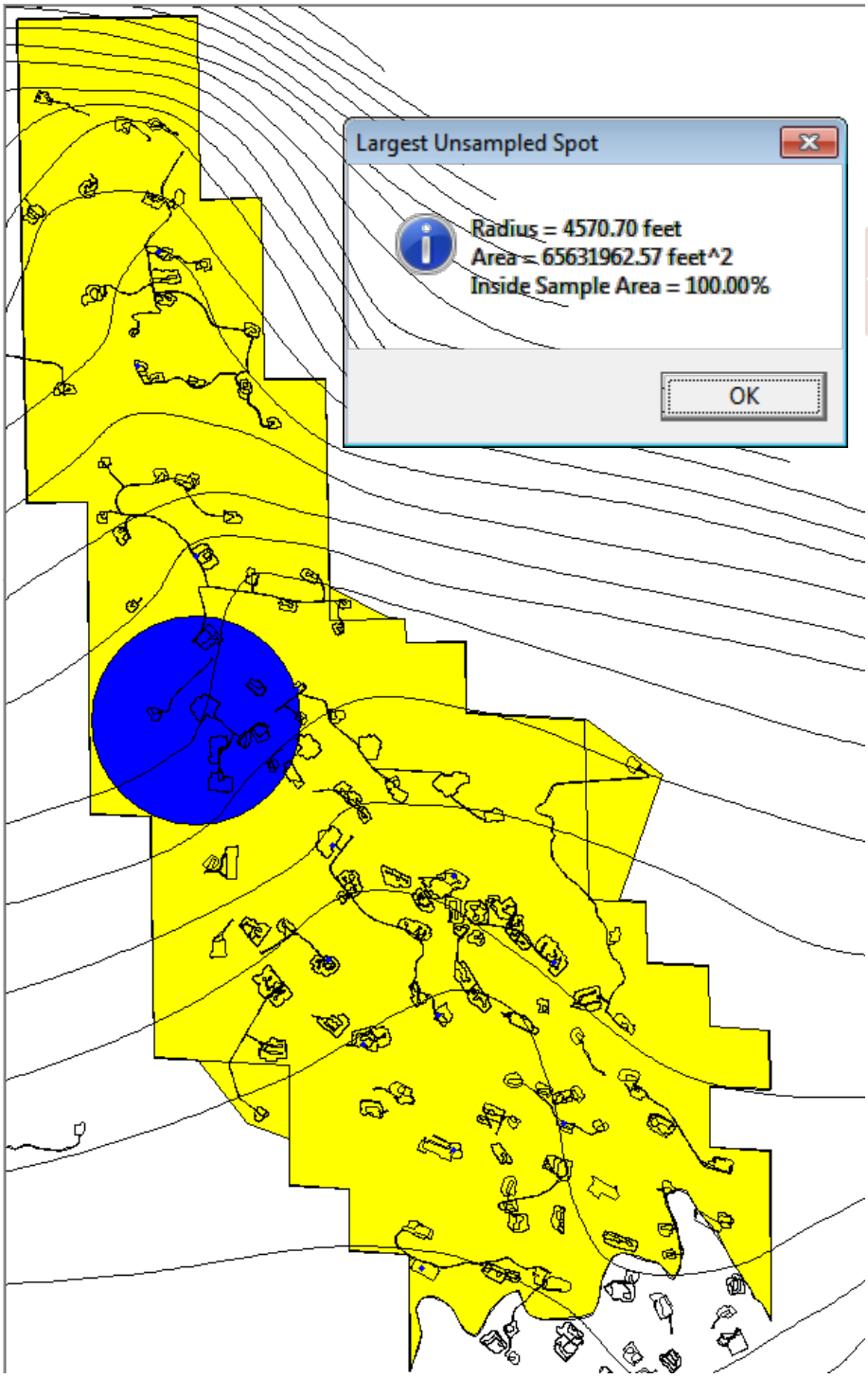
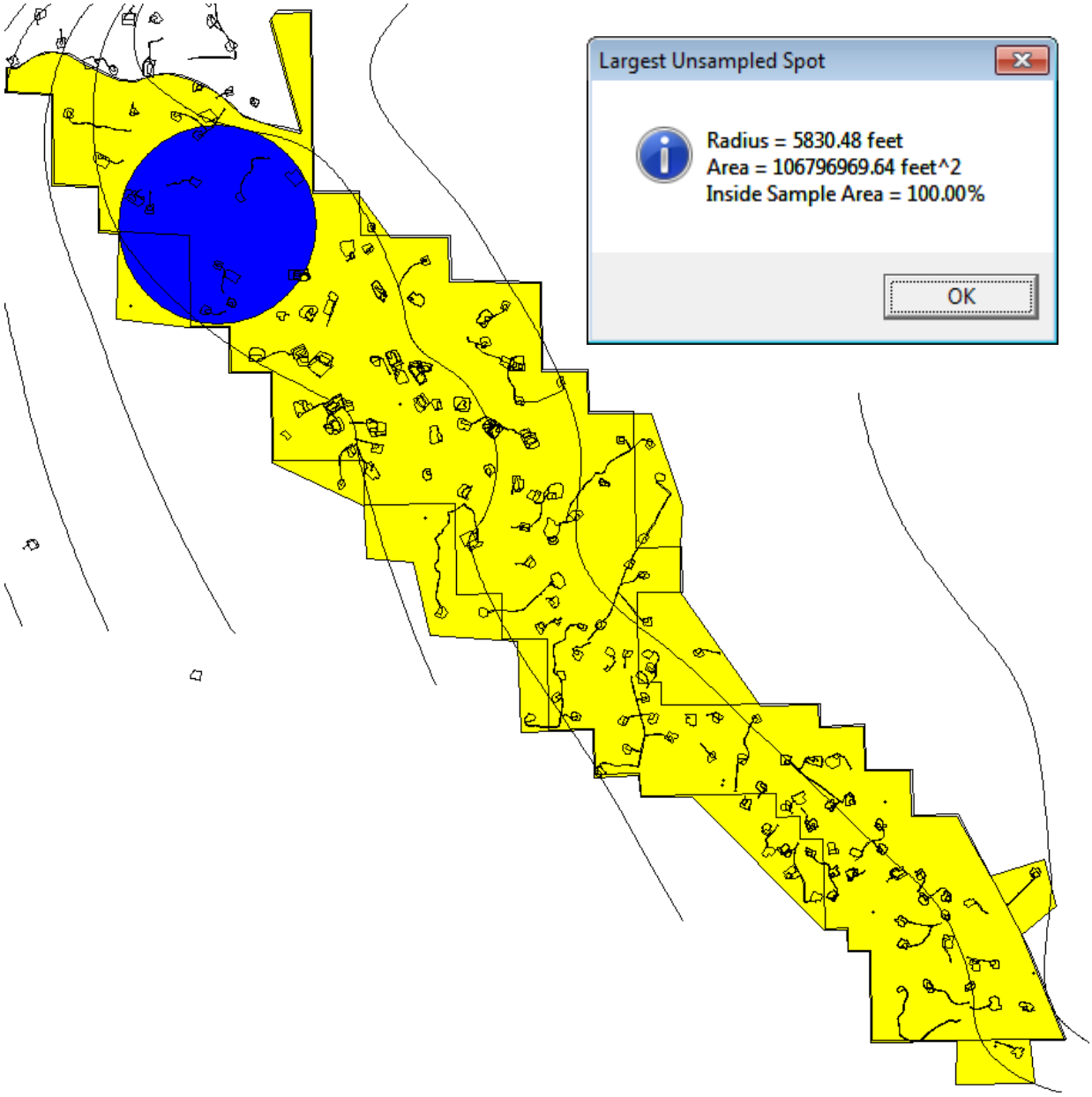
*North Zone – All existing wells:*



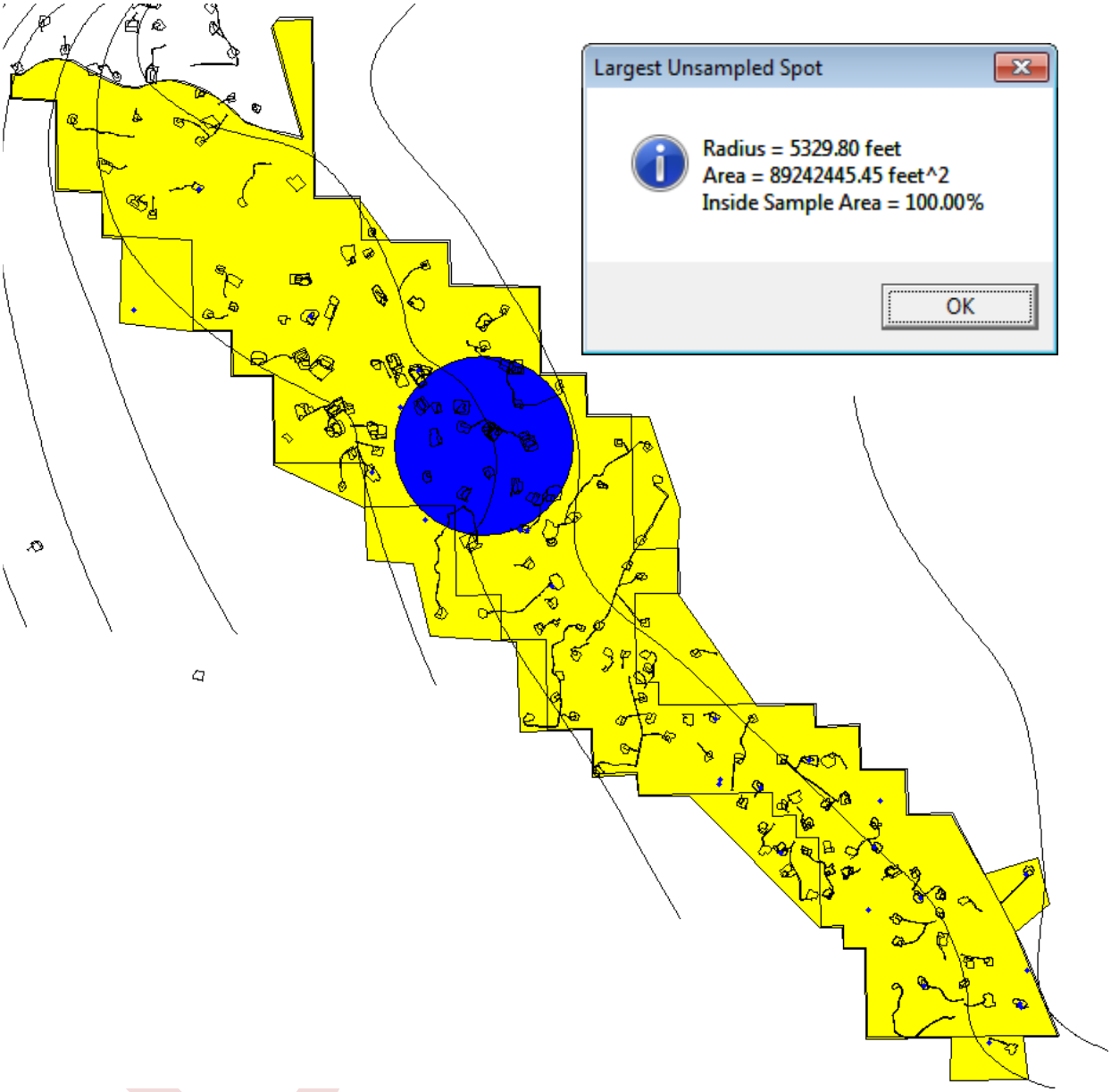
*North Zone – Added 1 new well and removed 29 redundant wells:*



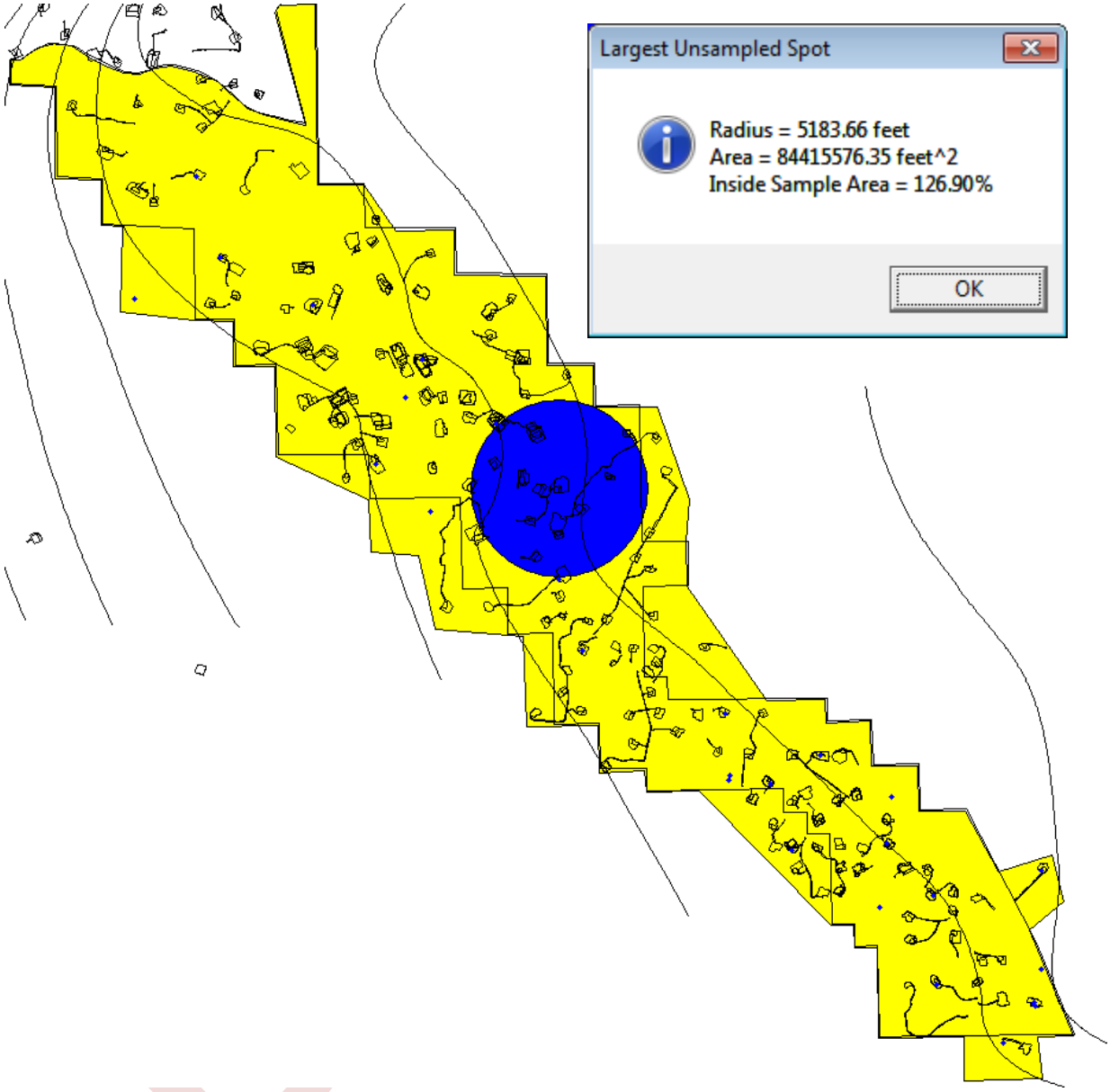
*South Zone – All existing wells:*



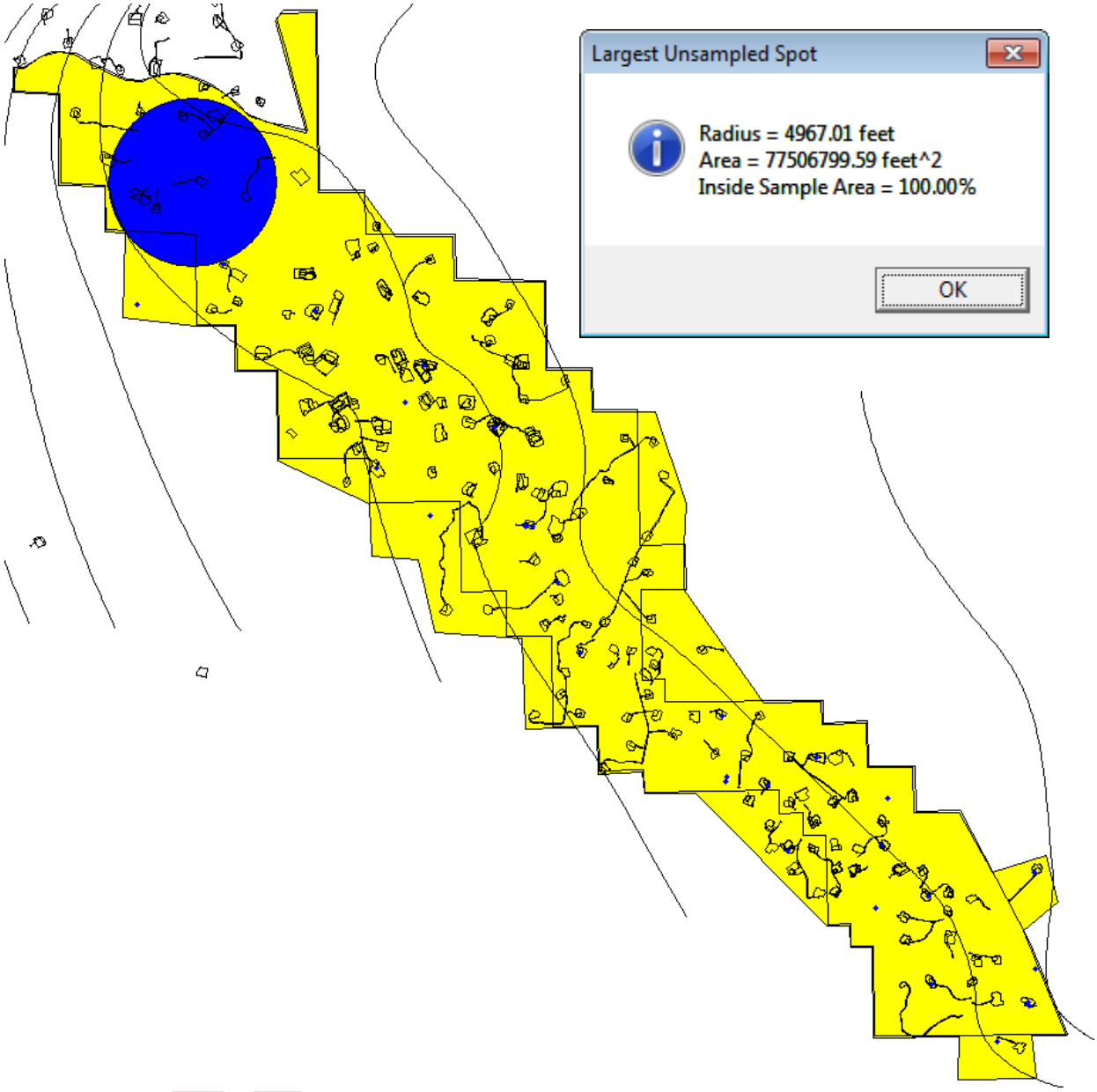
*South Zone – Added 1 new well and removed 16 redundant wells:*



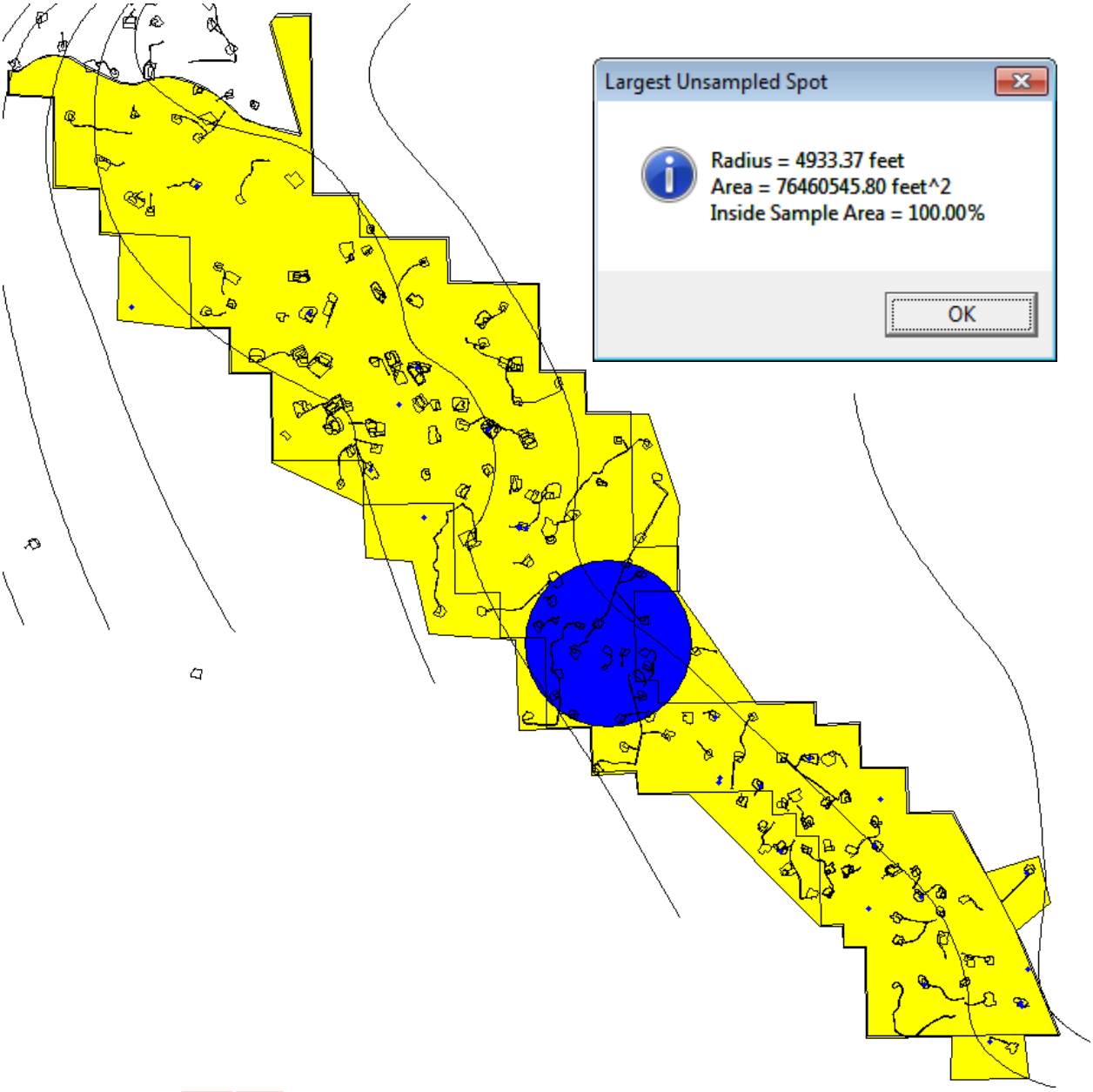
*South Zone – Added 1 new well and removed 1 redundant well:*



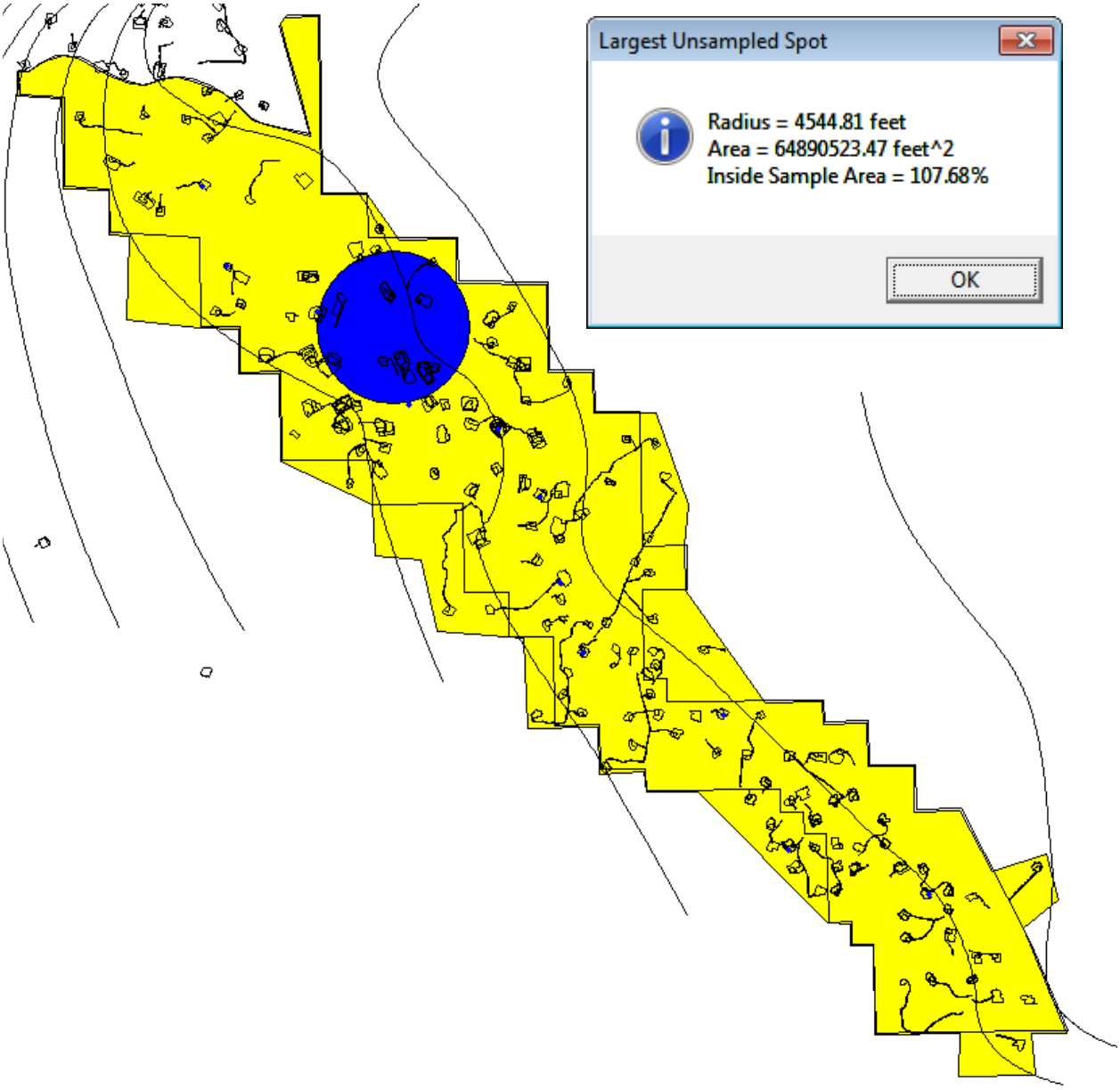
*South Zone – Added 1 new well and removed 1 redundant well:*



*South Zone – Added 1 new well:*



*South Zone – Added 1 new well:*

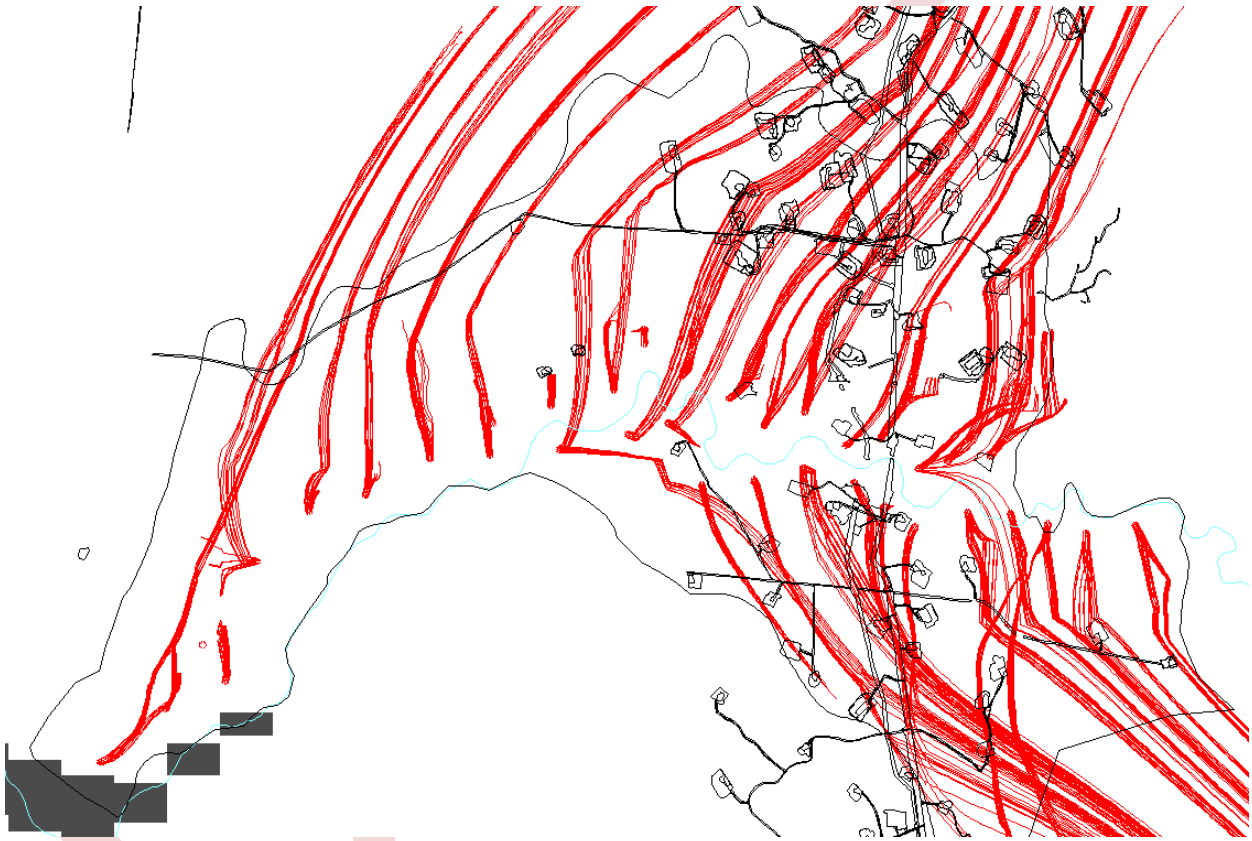



*<u>Note</u>: After completing the spatial analysis described above, further investigation of the proposed monitoring network revealed that one existing well selected for monitoring in the South Zone had been plugged and abandoned. Consequently, a new monitoring well for this sample area is necessary to replace the plugged and abandoned well. The total number of monitoring wells required in the South Zone remained the same however, the number of new wells increased to a total of 6.*

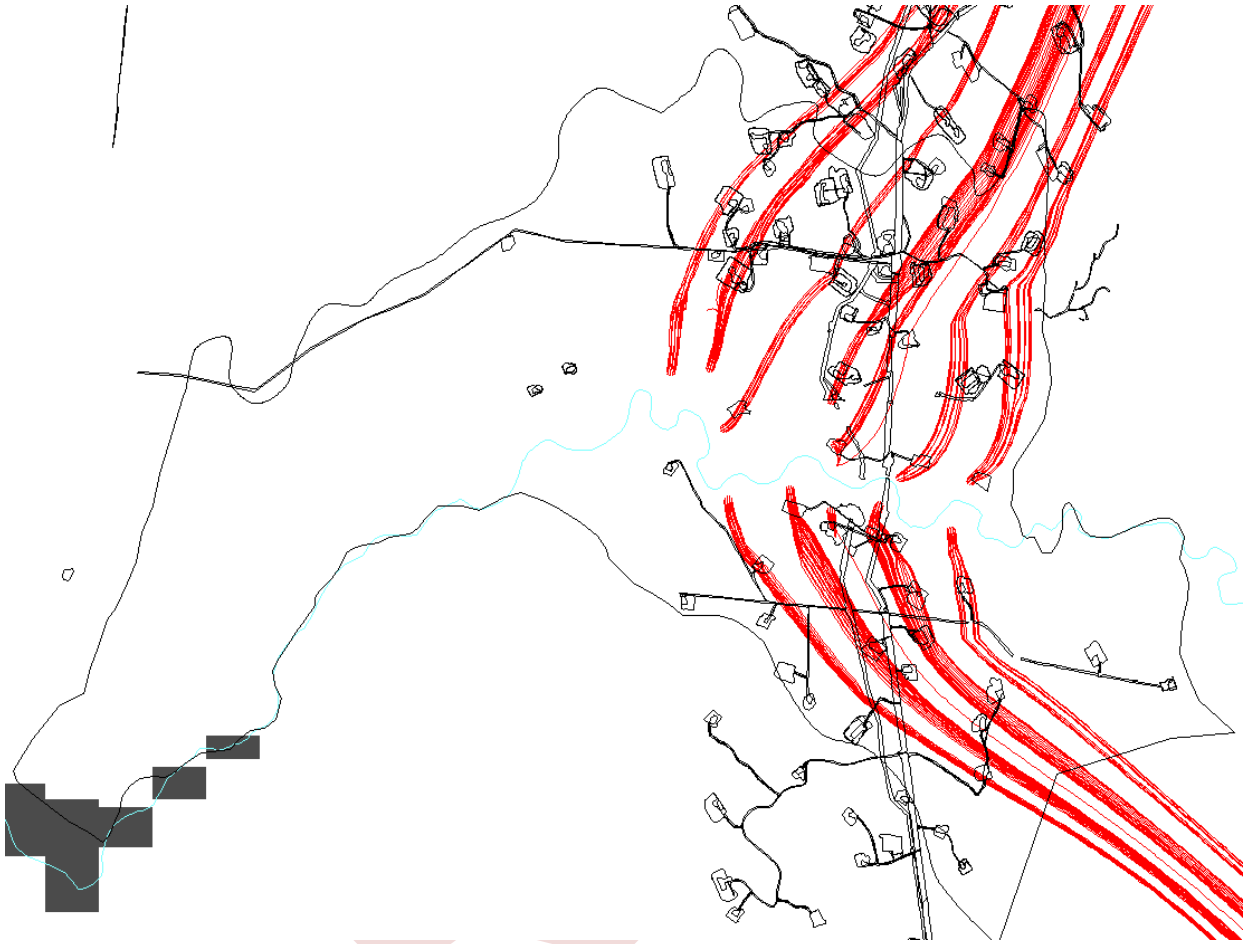
**River Corridor Envelope**

The following images are screen shots of particle tracking results in the Wasatch RCE based on the methods described above. The teal-colored line depicts the New Fork River, black lines depict potential sources (including footprints of existing natural gas well pads) and the RCE outline, and red lines depict reverse particle tracks from proposed monitoring wells. Note that proposed monitoring well locations would be located at the end of the red-colored reverse particle tracks. **Figure 4A-3** presents the final monitoring well locations, potential sources, and expected capture zones for the monitoring wells.

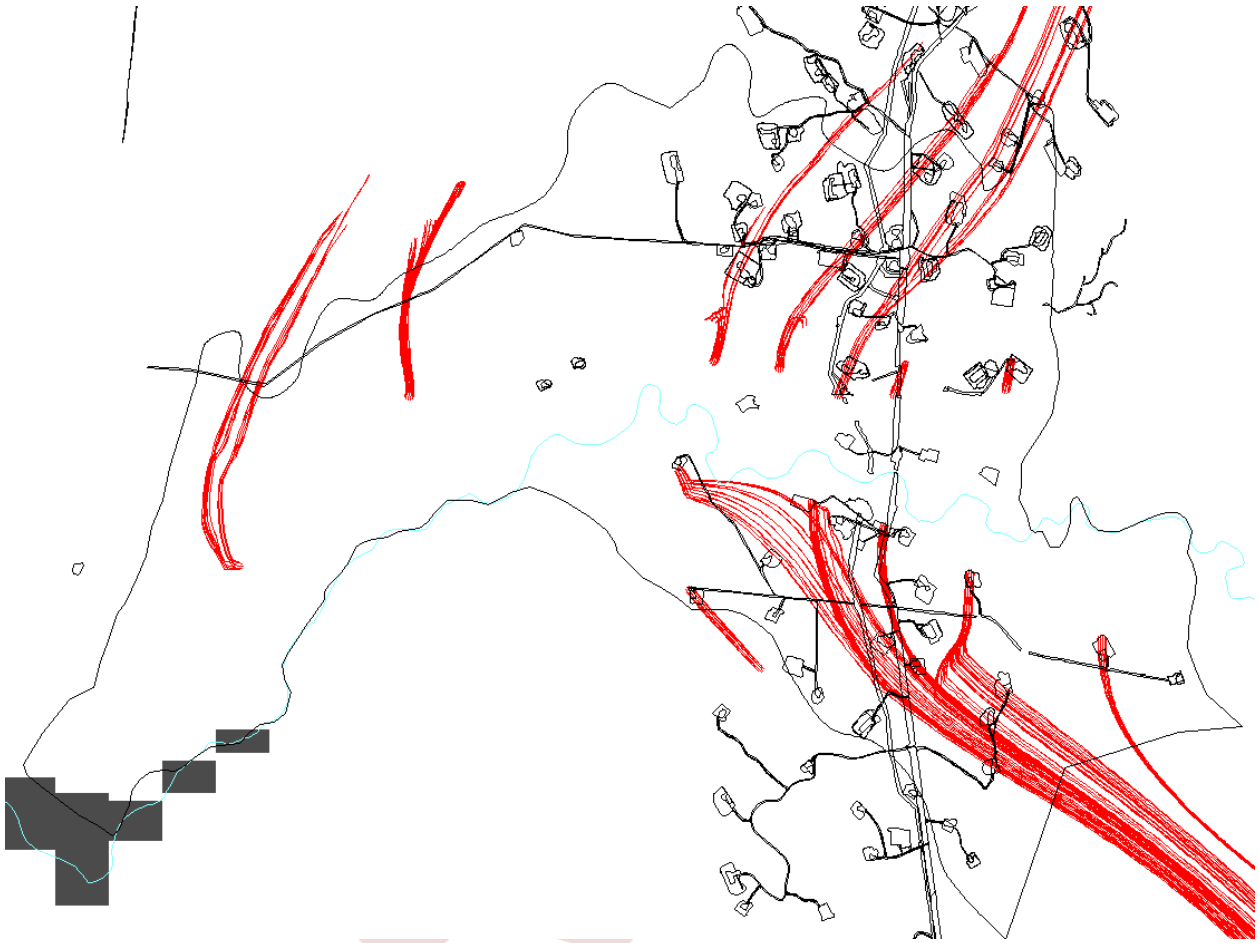
*Original locations:*



*Locations optimized based on 2,100 foot width:*



*Locations optimized based on the hydrogeologic conceptual model (AMEC, 2102) and location of potential receptors in relationship to potential sources:*



## CONCLUSIONS

Results of this analysis provide adequate spatial coverage in the three monitoring areas and sufficient early detection of potential degradation in the Wasatch and Alluvial HSUs as well as fulfill the objectives listed above. The chart below summarizes results of the completed analysis for the three different monitoring areas.

| Area | Existing Wells | New Wells | Total |
|---|---|---|---|
| North Zone | 12 | 1 | 13 |
| Wasatch RCE | 0 | 13 | 13 |
| Alluvial RCE | 4 | 0 | 4 |
| South Zone | 5 | 6 | 11 |
| **TOTALS** | **21** | **20** | **41** |

**Table 4A-1** lists the proposed monitoring wells and **Figure 4A-4** presents the well locations.

## REFERENCES

**AMEC Environment & Infrastructure, Inc. (AMEC), 2012**. Technical Report – Hydrogeologic Data Gaps Investigation, Interim Plan, Pinedale Anticline Project Area ROD, Sublette County, Wyoming, May.

_____, **2013a**. Final Numerical Groundwater Modeling Report, Interim Plan. Pinedale Anticline Project Area ROD, Sublette County, Wyoming. October.

_____, **2013b**. Final Technical Report, Evaluation of Low-Level Petroleum Hydrocarbon Compounds Detected in Groundwater, Interim Plan. Pinedale Anticline Project Area ROD, Sublette County, Wyoming. October.

**Bedessem, M.E., et al., 2005**. Aquifer Prioritization for Ambient Groundwater Monitoring. Ground Water Monitoring & Remediation 25, no. 1: 150–158. Winter 2005.

**BLM, see U.S. Department of the Interior, Bureau of Land Management**

**Geomatrix Consultants, Inc. (Geomatrix), 2002**. Groundwater Vulnerability from Exploration and Production Operations in the Pinedale Anticline Area, Sublette County, Wyoming. Unpublished report prepared for Shell Exploration and Production, Inc. May.

**Geomatrix. 2008**. Final Interim Groundwater/Aquifer Pollution Prevention, Mitigation, and Monitoring Plan (Interim Plan). Pinedale Anticline Oil and Gas Exploration and Development Project, Sublette County, Wyoming. Prepared for U.S. Department of Interior, Bureau of Land Management, Pinedale Field Office, Wyoming Department of Environmental Quality, Water

Quality Division, U.S. Environmental Protection Agency, Region 8, Shell Rocky Mountain Production, Questar Market Resources, and Ultra Resources, Inc. December.

**Hamerlinck, J.D., and Ameson, C.S., 1998**. Wyoming Ground Water Vulnerability Assessment Handbook: University of Wyoming, Laramie, Wyoming, Spatial Data Visualization Center, Report SDVC 98-01, 2 Volumes.

**Pacific Northwest National Laboratory (PNNL), U. S. Department of Energy, 2014**. Visual Sample Plan, Version 7.0, accessed at http://vsp.pnnl.gov/.

**U.S. Department of Interior, Bureau of Land Management (BLM), 2008a**. Record of Decision for the Supplemental Environmental Impact Statement, Pinedale Anticline Oil and Gas Exploration and Development Project. Sublette County, Wyoming. September 12.

Attachments: Figure 4A-1
Figure 4A-2
Figure 4A-3
Figure 4A-4
Table 4A-1

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# FIGURES

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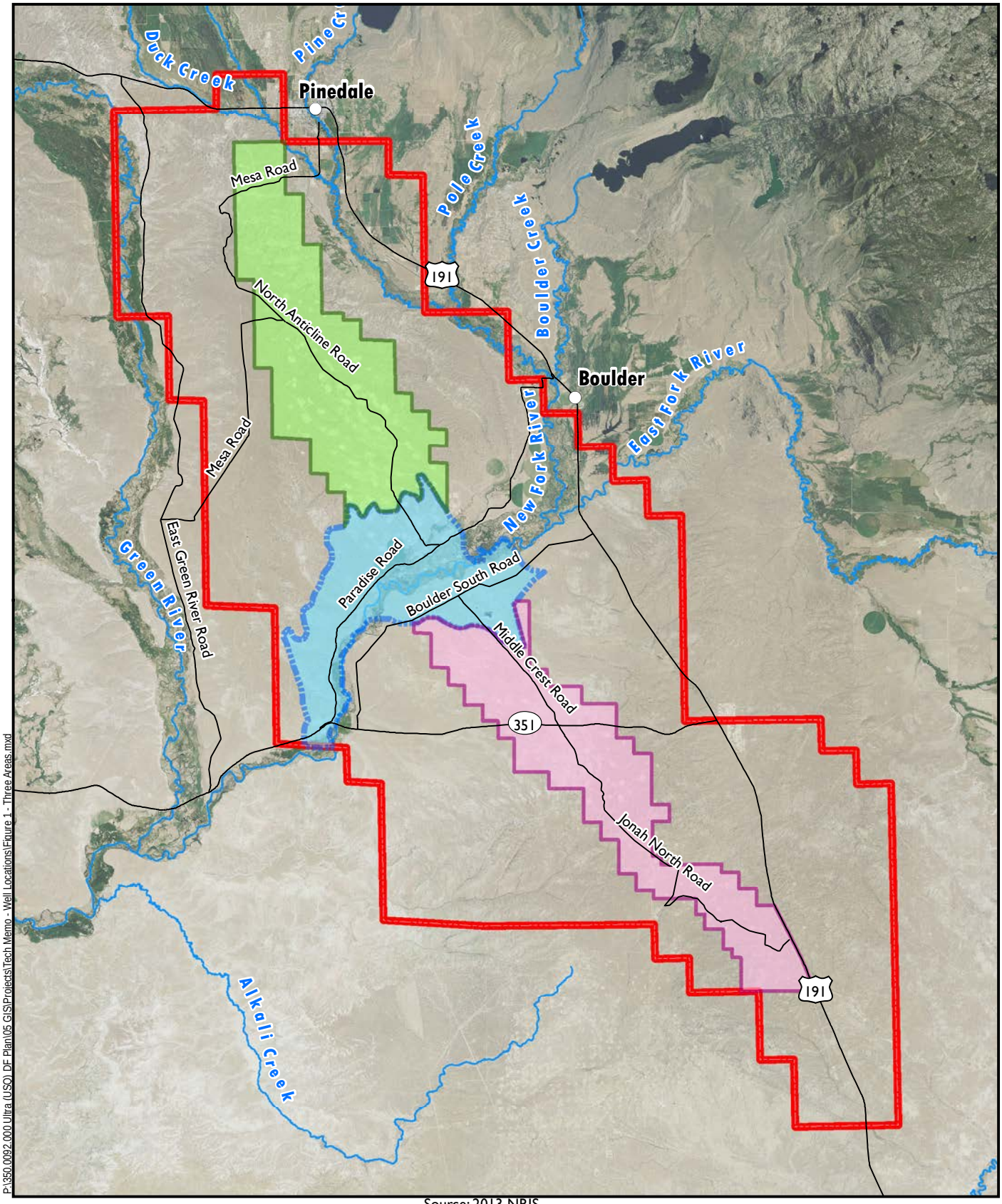


Source: 2013 NRIS

P:\350.0092.000 Ultra (USO) DF Plan\05 GIS\Projects\Tech Memo - Well Locations\Figure 1 - Three Areas.mxd

N

0 Miles 4

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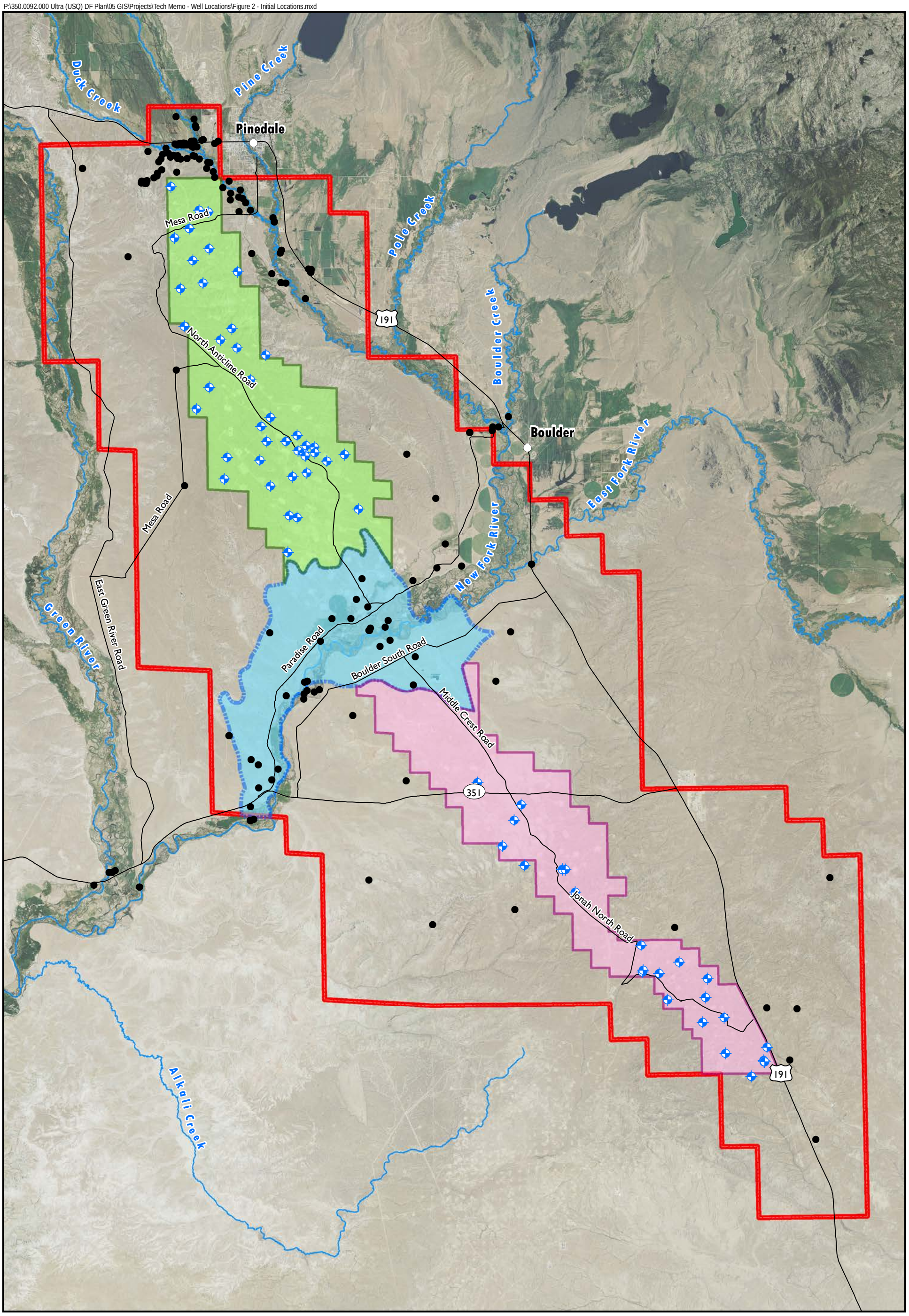
NewFields

North Zone
South Zone
River Corridor Envelope
Pinedale Anticline Project Area

Monitoring Areas
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4A-1

P:\350.0092.000 Ultra (USQ) DF Plan\05 GIS\Projects\Tech Memo - Well Locations\Figure 2 - Initial Locations.mxd




Source: 2013 NRIS

N

0 Miles 2.5

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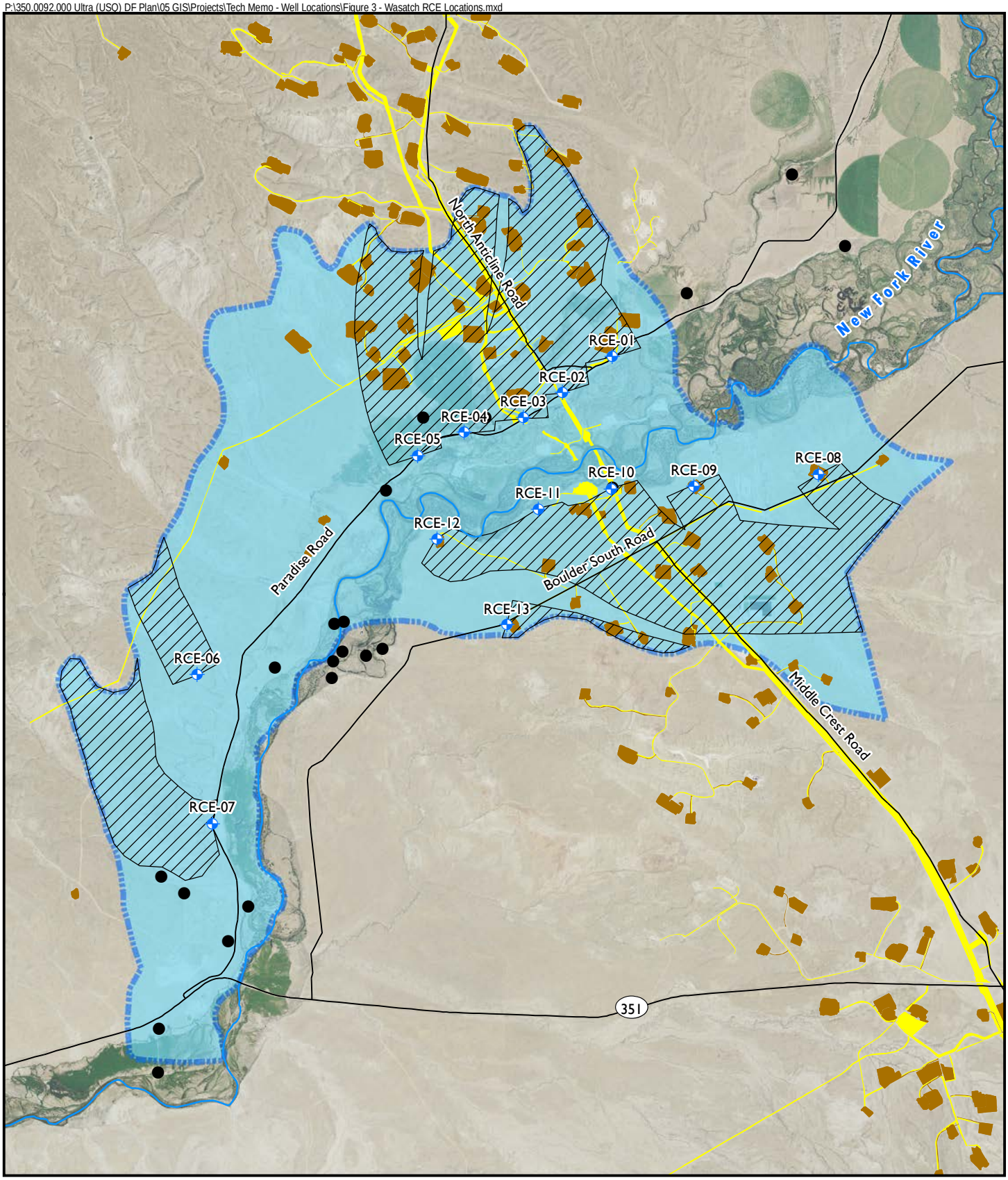
NewFields

- Removed from North and South zone analysis
- Retained for North and South zone analysis
- North Zone
- South Zone
- River Corridor Envelope
- Pinedale Anticline Project Area

**Initial Wells Used for Spatial Analysis**
**Pinedale Anticline Project Area**
**Sublette County, Wyoming**
**FIGURE 4A-2**

P:\350.0092.000 Ultra (USO) DF Plan\05 GIS\Projects\Tech Memo - Well Locations\Figure 3 - Wasatch RCE Locations.mxd




Source: 2013 NRIS

N

0 6,000 Feet

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Monitoring Well

Domestic Well

Estimated Capture Zone

**Potential Source**

Pipeline

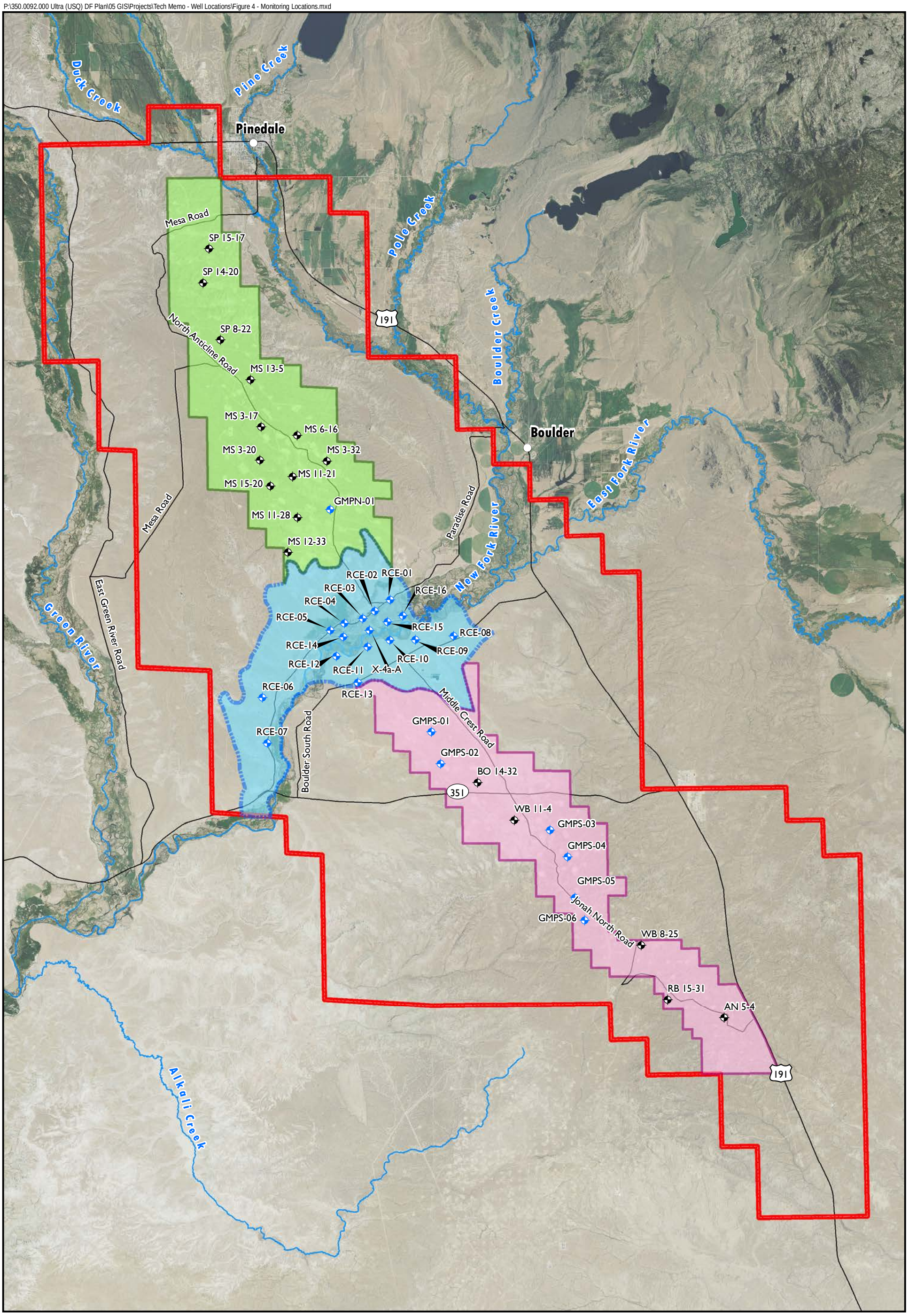
Well Pad

River Corridor Envelope

NewFields

**Wasatch RCE Monitoring Wells**
**Pinedale Anticline Project Area**
**Sublette County, Wyoming**
**FIGURE 4A-3**

P:\350.0092.000 Ultra (USQ) DF Plan\05 GIS\Projects\Tech Memo - Well Locations\Figure 4 - Monitoring Locations.mxd




Source: 2013 NRIS

N

0 Miles 2.5

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NewFields

Monitoring Well
Industrial Water Supply Well
South Zone
North Zone
River Cooridor Envelope
Pinedale Anticline Project Area

PAPA Groundwater Monitoring Locations
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4A-4

## TABLE

## TABLE 4A-1

### Proposed Wells for the Groundwater Monitoring Network

| AREA or ZONE | WELL NAME | SCCD ID | NATURAL GAS PAD NAME | HSU | EXISTING | NEW | TOTAL DEPTH | | COORDINATES[1] | | OWNERSHIP - SURFACE MANAGEMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Existing Wells (feet) | Anticipated for New Wells (feet) | Northing | Easting | |
| NORTH | MS 11-21 | AMI154 | MS 11-21 | Wasatch | X | | 910 | | 15,523,864 | 1,950,885 | QEP - BLM |
| | MS 11-28 | AMI159 | MS 11-28 | Wasatch | X | | 905 | | 15,517,921 | 1,951,565 | Ultra - BLM |
| | MS 12-33 | AMI167 | MS 12-33 | Wasatch | X | | 1,000 | | 15,512,795 | 1,950,170 | Ultra - BLM |
| | MS 13-5 | AMI029 | MS 13-5 | Wasatch | X | | 940 | | 15,538,048 | 1,944,707 | QEP - BLM |
| | MS 15-20 | AMI239 | MS 15-20 | Wasatch | X | | 1,120 | | 15,522,558 | 1,947,624 | QEP - BLM |
| | MS 3-17 | AMI112 | MS 3-17 | Wasatch | X | | 1,200 | | 15,531,222 | 1,946,282 | QEP - BLM |
| | MS 3-20 | AMI027 | MS 3-20 | Wasatch | X | | 940 | | 15,526,279 | 1,946,080 | QEP - BLM |
| | MS 3-22 | AMI014 | MS 3-22 | Wasatch | X | | 772 | | 15,526,170 | 1,955,913 | QEP - BLM |
| | MS 6-16 | AMI114 | MS 6-16 | Wasatch | X | | 1,000 | | 15,529,939 | 1,951,551 | QEP - State of Wyoming |
| | SP 14-20 | AMI139 | SP 14-20 | Wasatch | X | | 1,000 | | 15,552,193 | 1,937,755 | QEP - BLM |
| | SP 15-17 | AMI111 | SP 15-17 | Wasatch | X | | 940 | | 15,557,192 | 1,938,670 | QEP - BLM |
| | SP 8-32 | AMI205 | SP 8-32 | Wasatch | X | | 1,090 | | 15,543,866 | 1,940,325 | QEP - BLM |
| | GMPN-01 | NA | MS 6-27 | Wasatch | | X | | 250 - 300 | 15,519,064 | 1,956,395 | Ultra - BLM |
| RIVER CORRIDOR ENVELOPE | RCE-01 | NA | NA | Wasatch | | X | | 100 - 200 | 15,505,864 | 1,965,144 | County Road ROW |
| | RCE-02 | NA | NA | Wasatch | | X | | 100 - 200 | 15,504,228 | 1,962,891 | County Road ROW |
| | RCE-03 | NA | NA | Wasatch | | X | | 100 - 200 | 15,503,108 | 1,961,134 | County Road ROW |
| | RCE-04 | NA | NA | Wasatch | | X | | 100 - 200 | 15,502,442 | 1,958,472 | County Road ROW |
| | RCE-05 | NA | NA | Wasatch | | X | | 100 - 200 | 15,501,415 | 1,956,366 | County Road ROW |
| | RCE-06 | NA | NA | Wasatch | | X | | 100 - 200 | 15,491,554 | 1,946,445 | BLM |
| | RCE-07 | NA | NA | Wasatch | | X | | 100 - 200 | 15,484,849 | 1,947,143 | County Road ROW |
| | RCE-08 | NA | BR 16-7 | Wasatch | | X | | 100 - 200 | 15,500,575 | 1,974,417 | Ultra - BLM |
| | RCE-09 | NA | RS 15-12 | Wasatch | | X | | 100 - 200 | 15,500,028 | 1,968,814 | Ultra - Private |
| | RCE-10 | NA | JN 16-11 | Wasatch | | X | | 100 - 200 | 15,499,918 | 1,965,101 | Ultra - Private |
| | RCE-11 | NA | JN 3-14 | Wasatch | | X | | 100 - 200 | 15,498,996 | 1,961,819 | Ultra - Private |
| | RCE-12 | NA | SW 3-15 | Wasatch | | X | | 100 - 200 | 15,497,644 | 1,957,247 | QEP - Private |
| | RCE-13 | NA | RS 4-23 | Wasatch | | X | | 100 - 200 | 15,493,783 | 1,960,404 | Ultra - Private |
| | X-4a-A | NA | JN 11-11 | Alluvial | X | | 20 | | 15,501,438 | 1,962,124 | Ultra - Private Land |
| | RCE-14 | NA | JN 15-10 | Alluvial | X | | 13 | | 15,500,425 | 1,958,285 | Ultra - Private Land |
| | RCE-15 | NA | VB 8-11 | Alluvial | X | | 13 | | 15,502,653 | 1,964,758 | Ultra - Private Land |
| | RCE-16 | NA | VB 3-12 | Alluvial | X | | 13 | | 15,503,471 | 1,966,973 | Ultra - Private Land |
| SOUTH | AN 5-4 | AMI131 | AN 5-4 | Wasatch | X | | 550 | | 15,444,730 | 2,014,015 | Linn Energy - BLM |
| | BO 14-32 | AMI280 | BO 14-32 | Wasatch | X | | 700 | | 15,479,112 | 1,977,944 | Ultra - BLM |
| | RB 15-31 | AMI189 | RB 15-31 | Wasatch | X | | 740 | | 15,447,371 | 2,005,747 | Linn Energy - BLM |
| | WB 11-4 | AMI301 | WB 11-4 | Wasatch | X | | 800 | | 15,473,663 | 1,983,316 | Ultra - BLM |
| | WB 8-25 | AMI242 | WB 8-25 | Wasatch | X | | 670 | | 15,455,310 | 2,001,889 | Ultra - BLM |
| | GMPS-01 | NA | BR 5-30 | Wasatch | | X | | 100 - 200 | 15,486,528 | 1,971,152 | Ultra - BLM |
| | GMPS-02 | NA | BR 6-31 | Wasatch | | X | | 150 - 250 | 15,481,841 | 1,972,550 | Ultra - BLM |
| | GMPS-03 | NA | WB 3-10 | Wasatch | | X | | 300 - 400 | 15,472,189 | 1,988,568 | Ultra - BLM |
| | GMPS-04 | NA | WB 16-10 | Wasatch | | X | | 400 - 500 | 15,468,253 | 1,991,107 | Ultra - BLM |
| | GMPS-05 | NA | WB 4-23 | Wasatch | | X | | 500 - 600 | 15,462,303 | 1,992,215 | Ultra - BLM |
| | GMPS-06 | NA | WB 11-23 | Wasatch | | X | | 500 - 600 | 15,458,969 | 1,993,604 | Ultra - BLM |

Notes:

RCE - River Corridor Envelope

SCCD ID - Sublette County Conservation District Identification Number

HSU - Hydrostratigraphic Unit as defined in AMEC (2012)

ROW - Right of Way

NA - Not applicable

Footnotes:

1 - Northing and Easting values are in feet relative to UTM Zone 12; coordinates for new wells are approximate